Range of Bluetooth Low Energy Beacons in Relation to Their Transmit Power

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Abstract - *In this paper, we answer the question of whether or not the range at which Bluetooth Low Energy (BLE) beacons can be detected is related to the transmit power and position of the beacons. We used an Android smartphone app developed for our research and a small USB BLE beacon. Experiments were conducted at each of the sixteen preset power settings of the BLE beacon to determine the range at which the smartphone app lost connection to the BLE beacon. We show that the power setting of the BLE beacon did, in fact, have a significant impact on the overall range of the BLE beacon, as did its positioning. Our findings confirm that these BLE beacons can indeed be configured to have different ranges and thereby be used more reliably for indoor localization.*

Keywords: Android, BLE, Beacon, Range

1 Introduction

Tackling the problem of indoor localization is an important next step in the future of the Internet of things. With effective indoor localization, we can determine where someone is within a building with a reasonable level of accuracy. This ability would allow for advancements in indoor experiences in public places, offices, and private residences. Museums and historical sites, for example, are already starting to use beacon technology to enrich a visitor's experience by providing them with extra information when they stand in front of an exhibit. Leicester Castle [1] is a prime example of a historical site using this technology to enrich their visitors' experiences.

There is still a vast amount of room for this technology to grow in terms of accuracy, efficiency, and use. Acknowledging its current level of use, better indoor localization could lead to many more interesting ways to integrate the technology into our lives. "Smart Houses" would become easier to implement. Restaurants, airports, art galleries, places of business, and government offices, to name just a few, could also utilize this technology to improve a visitor's and an employee's respective experiences.

As this paper discusses later in section 2, there have been many approaches to indoor localization. In the past, systems have been set up with a variety of different technologies, such as Wi-Fi [2] [3] and ZigBee [4], another low power standard for wireless technology. More recently, Bluetooth Low Energy (BLE) beacons have been utilized in indoor localization systems [5].

Aside from this kind of research, there have also been studies examining how to make the best use of this technology and indoor localization as a whole. Our research does not address any of these issues. Instead, our work focuses solely on BLE beacons and their capabilities.

The question that this paper attempts to answer is the following: does the transmit power setting of BLE beacons and its position have a significant effect on their maximum and reliable ranges? Our research answers this question through a series of different and unique experiments, each one representing different real-life scenarios, conducted on Carleton University's campus.

In the following section we discuss prior research that has been done on the properties of BLE beacons. Then, in section 3, we cover our approach to our research, including the equipment and technology used, as well as the way in which our experiments were set up. Following that in section 4, we discuss and examine the results of each experiment. Finally, in section 5, we present our conclusions drawn from our work.

2 Background

We discuss the research that has already been conducted to examine properties of BLE beacons in this section. Research on placement, formulas, and other facets of localization using BLE technology are also discussed. While a significant amount of research has been done on the placement and efficiency of these BLE beacons, very little has been done to examine how the range of the beacons fluctuates or how accurate the manufacturers' stated ranges are.

The Global-Positioning-System (GPS) has long been used to accurately determine one's outdoor location. However, the GPS is not sufficient for indoor localization as steel and concrete block and distort the satellite signal. Due to this complication of the GPS, there have recently been studies on how to accurately and efficiently accomplish the task of indoor localization. In the past, there have been approaches using many different technologies. Wi-Fi is one of these technologies that has been recently used for such localization. For example, [2] and [3] cover two novel approaches to using Wi-Fi technology for indoor localization. However, the use of BLE beacons for indoor localization has been the focus of more recent research due to their cost and power efficiency [5].

There are currently three major specifications for BLE beacons, the iBeacon Specification [6], developed by Apple, the AltBeacon Specification developed by Radius Networks [7], and Google’s new Eddystone Beacon Specification [8]. These specifications are all very similar in that the BLE beacons will transmit a small amount of data in which one can find at least a unique identification (UUID) code, two other identification numbers, and a the power level measured at 1m. Other data may also be transmitted depending upon the specification used. It should be noted that Eddystone beacons can be configured to transmit a URL instead of the UUID, which still follows the idea that a very small amount of data is transmitted by the BLE beacon. A full explanation of Eddystone beacons and their other features, such as security and advanced management, are available on Google’s Eddystone website [8].

Most new smartphones are now BLE capable, that is to say that they are capable of connecting with and receiving data from BLE beacons in the same way that they are able to connect with, receive, and transmit data to Bluetooth devices [9]. As a result of this, it is becoming more practical to use BLE beacons to create an ad hoc indoor localization network. Much research on how to setup this BLE ad hoc network and how to make use of it has been conducted [10] [11] [12] [13] [14] [15] [16].

Indoor localization is one area of BLE beacon research. For example, recent research has been looking at how to best set up an environment for maximum accuracy and efficiency, as is done here [10]. [10] makes note of the variety of different placement techniques that one can employ for the purpose of localization such as triangulation, trilateration, multilateration, and finally, the method covered in that paper, cell-based localization.

Another example, [11], demonstrates how the placement of beacons in and around rooms can lead to a more accurate form of indoor localization. In this case, the study used a large number of beacons placed both inside and outside of the classroom for the purpose of a positioning technique they describe as template matching.

Using BLE close proximity localization outside has also been considered [12]. This study places the BLE beacons outside near tourist spots, and pushes tourists information once they come within a certain range. While this research does not actually concern itself with indoor localization, it still has an impact on how we use BLE technology and techniques with which we can best employ it.

Another common area of research of BLE technology looks at new mathematical formulas for calculating the distance between a BLE beacon and a BLE capable device. For example, [13] covers calculating the distance between a BLE capable device and a BLE beacon using the received signal strength indication (RSSI) in tandem with multilateration to discern a general position. [14] extensively discusses a unique fingerprinting positioning technique for BLE beacons.

Research has also been conducted in potential use cases for a BLE indoor localization system. A check-in-check-out (CICO) system was created using BLE beacons [15]. It was compared against other attendance taking methods at events. Also, BLE technology’s use in a university setting as an attendance apparatus was also examined [16]. In this study, a BLE beacon network was used and combined with other technology to create an easy to use attendance system for students and teachers.

While all of this research has paved the way for the improvement of BLE indoor localization, there has been very little research done on the maximum and reliable ranges of these beacons depending on their transmit power level and the environment in which they are installed.

Our research does not cover the accuracy of BLE beacons or the most efficient way to setup a BLE beacon environment. Instead, our work focuses on the reliable range of the beacons, which is defined here as the range at which a BLE capable device can reliably connect or stay connected to a BLE beacon. The maximum range of the beacons was also recorded, and is defined here as the range at which the BLE capable device lost connection to the BLE beacon for more than 10 seconds. Then we manipulate the transmit power setting of the BLE beacon, and examine whether or not this has an effect on the maximum or the reliable ranges of the BLE beacon. Graphs showing the reliable distance of the beacons are presented in this paper.

Research in this area, in combination with the other research on BLE beacons and their capabilities, is imperative to the research of indoor localization. This paper aims to fill in this gap in the examination of BLE beacons with the attempt of getting closer to the full view of how they work.

An accurate view of how BLE beacons work and their capabilities could lead to either an indoor localization standard using BLE beacons that is as relatively accurate, if not more relatively accurate, than the GPS, or it could lead to the development of new technology that will allow us to achieve reliable indoor localization comparable to that of the GPS. When this happens, museums, airports, hotels, universities, and even private residences will be able to enrich their indoor experiences in the same way that the GPS has enriched our outdoor experiences today.

3 Approach

An explanation of the experiments is presented in this section. Here, the equipment used in the experiments, the technologies used in developing the tools used in the experiments, the ways in which the experiments themselves were setup, and the shortcomings of the experiments, are discussed.

3.1 Equipment Used

The experiments used for our research were conducted on an Android Nexus 5X smartphone [17], hardware manufactured by LG and software manufactured by Google. The Android Nexus 5X comes equipped with BLE technology and the basic Android OS, in this case, Android version 6.0.1.

The BLE beacon used for this research was a Radius Networks RadBeacon USB [18]. The USB beacon is able to plug into any USB outlet and function as a fully operational BLE beacon. It has 16 transmit power settings, ranging from 3dBm to -23dBm. Each power setting has a previously calibrated “measured power” setting. This power setting is measured at 1m from the beacon.

A 2015 MacBook Pro running OS X El Capitan 10.11.5 was used to store, organize, and present the data from each experiment.

3.2 Technology Used

An Android application was developed specifically for our research. It uses the Android Beacon Library [19] provided by Radius Networks in order to detect and record nearby beacon data. It also makes use of the Retrofit 2.0 framework [20] to send HTTP requests to a web-service. This application was developed in Android Studio.

It should be noted that the Android Beacon Library requires that 10 seconds pass before it determines whether or not a device is still in range of a previously seen BLE beacon. This value can be changed, but for the purpose of our experiment it was left at 10 seconds.

A MySQL [21] database is used by this application to store the data from each experiment. It runs on the MacBook Pro using MAMP [22]. This database was managed and viewed using MySQLWorkbench [21].

The Android application communicates over Wi-Fi with the MySQL database using a Jersey [23] web-service that makes use of Hibernate framework [24] for its object-relational-mapping (ORM). This web-service was written using the Spring STS IDE [25] and the it was deployed using the open source software Apache Tomcat [26].

3.3 General Setup and Procedure

Each experiment had some general setup similarities. The RadBeacon USB was plugged into an Apple 12W USB Power Adapter, which was itself plugged into an electrical wall outlet. A tape measure was used to measure distance from the beacon, and a marker with the metre number on it was placed at every metre.

In each experiment, the RadBeacon USB’s power level started out at the maximum setting, which is 3dBm, with a measured level calibrated by default of -66dBm. After the Android Nexus 5X either lost connection to the RadBeacon USB, or reached the maximum distance of the experiment (this will vary depending on the experiment), the application was stopped and the RadBeacon USB’s power level was reduced to the next lowest power setting. This procedure was followed until the minimum power setting was chosen, which is -23dBm, with a measured power level calibrated by default of -94dBm.

During the measuring of each power setting, the beacon data as well as the Android Nexus 5X’s internal time is being sent to the MySQL database approximately every second. The data being sent includes the first unique identification code, the measured distance based on the Android Beacon Library’s formula, the measured power level (calibrated by the manufacturer, and sent as part of its transmission), the type of the beacon, and a boolean value stating whether or not the device is in range of the beacon.

In each experiment, the Android Nexus 5X directly faced the RadBeacon USB the entire time, with the goal of having minimal obstructions between the two devices.

3.4 Experiment I

The first experiment was conducted in a university lecture hall. The experiment was to examine the range of the RadBeacon USB on an upward incline. That is, due to the slant of the university lecture hall, if the RadBeacon USB was plugged in at the front of the room, then the distances from it would have to be measured going up the incline. The room had a maximum distance of 23 metres from the outlet. The distance measurements in this experiment began 1 metre from the outlet that the beacon was plugged into. This setup is shown in figure 1.

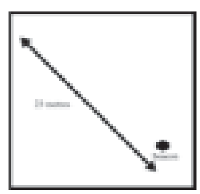

Figure 1

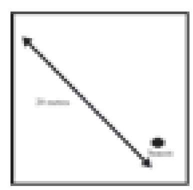

Figure 2

Figure 3

3.5 Experiment II

This experiment was conducted in the same university lecture hall as the first experiment. This experiment examined the range of the RadBeacon USB on a downward incline. Thus in this case, the RadBeacon USB was plugged in at the back of the room. Again, the same procedures noted in part C of this section were followed. The maximum distance in this case (being as the outlet was not directly across from the outlet used in the first experiment) was 20 metres. As before, the distance measurements in this experiment began 1 metre from the outlet that the beacon was plugged into. The setup of the experiment is shown here in figure 2.

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3.6 Experiment III

The goal of this experiment was to examine the range of the RadBeacon USB through a 182 centimetre thick concrete wall. This was conducted just outside of a university lecture hall (but still indoors). The RadBeacon USB was plugged into an outlet inside of the lecture hall. Due to the limitations of the area, the maximum distance here was only 4 metres. Measurements for this experiment began 1 metre from the outside of the wall. This setup can be found here in figure 3.

3.7 Experiment IV

To attempt to address the shortcomings of the previous experiment, another location was also measured to test the beacon's range through a wall. In this experiment, the RadBeacon USB's range was measured through 13 centimetres of drywall, a clear space of 139 centimetres, and another 14 centimetres of drywall. This adds up to a total of 166 centimetres. Here the maximum distance was 7 metres. Again, measurements for this experiment began 1 metre from the wall. This experiment is shown in figure 4.

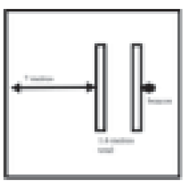

Figure 4

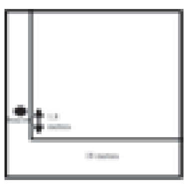

Figure 5

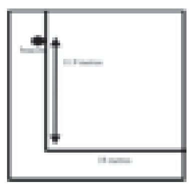

Figure 6

3.8 Experiment V

This experiment is the first of two conducted with the beacon plugged in around a corner. In this first experiment, the RadBeacon USB was plugged in 184 centimetres along the wall. Measurements for this experiment began 1 metre from the corner of the wall. The maximum distance in this case was 18 metres, as shown in figure 5.

3.9 Experiment VI

Illustrated in figure 6, this final experiment was conducted in the same location as the experiment described in part H of this section. The difference here is that the RadBeacon USB was plugged in 1191 centimetres along the wall. Again the maximum distance was 18 metres and measurements began 1 metre from the corner of the wall.

4 Results

We discuss the results of the experiments in this section. How the results relate to the context of each experiments, as well as how they can be applied or related to real-life situations is also covered in this section.

It is important to note in examining these following results that the goal of this paper is not to address accuracy of the BLE beacons nor is it to address efficient placement or layout of the BLE beacons. Instead, the purpose is to examine how the range of these BLE beacons changes in relation to their transmit power setting.

The following figures indicate the reliable distance of the BLE beacons. The reliable distance is the distance at which it first loses connection to the Android Nexus 5X device. In many cases it subsequently regained connection to the device, if only for a few more metres, this would not be sufficient for real world applications however. Thus, the reliable distances are more telling in this case.

Figures 7 and 8 show the results of the first two experiments. In the first experiment, the maximum distance was 23 metres, and in the second experiment, the maximum distance was 20 metres. Measurement beyond these distances was not possible due to the constraints of the location.

In these two figures, we can see that given a clear line of sight, more than half of the power settings are able to reach the full 23 metre and 20 metre lengths, respectively. When the range does begin to drop off, however, it drops off quickly.

Figures 9 and 10 show the results of the two experiments that examine the ranges through two different types of walls and different scenarios. The maximum distance in these two scenarios is considerably smaller than in the other four. This is because of both the location of the experiments as well as well as the fact that walls do have a significant impact on the overall range of the beacons.

Here, it is evident that while the walls do have an effect on the overall range of the BLE beacons, they can still be detected through the walls in both scenarios on every power setting. How BLE beacons behave near walls can also be an indicator of how they behave near closed doors. These experiments shed some light on necessary power settings to restrict access to the beacon to only one room.

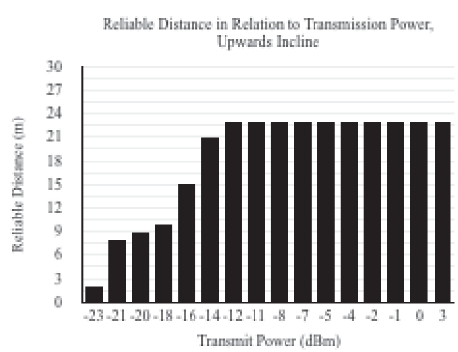

Figure 7. Minimal obstructions on an upwards include

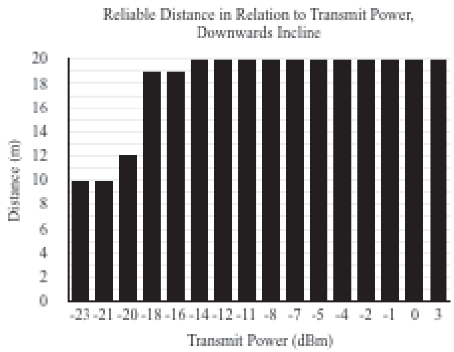

Figure 8. Minimal obstructions on an downwards incline. This graph maps to experiment II.

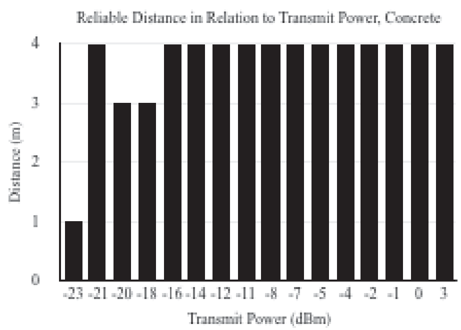

Figure 9. Minimal obstructions through a 182cm concrete wall. This graph maps to experiment III.

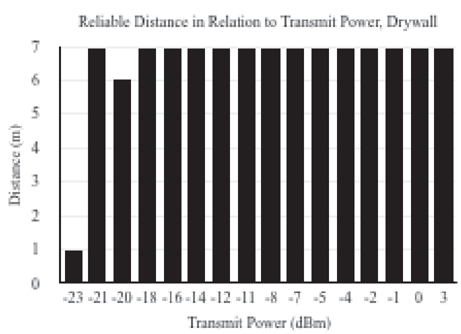

Figure 10. Minimal obstructions through 166cm drywall and space. This graph maps to experiment IV.

Finally, figures 11 and 12 below illustrate the results of the last two experiments. These two experiments were conducted in the same location but at different distances along the wall, as described above in section III. Note that in both of these cases the maximum distance is 18 metres, but that in the second experiment the furthest range reached is only 12 metres around the corner.

As is shown in the above figures, when the beacon is only a few metres up the wall, there is not much of a difference between this and the clear line of sight experiment. As expected, however, when the beacon is considerably further up the wall, it cannot reach the maximum distance and in fact drops off completely after the half way point of the power settings. This set of experiments relates to situations in which BLE beacons would be setup in hallways or near doorways where the door is constantly open.

All of these results demonstrate that the transmission power of the BLE beacons does in fact have a significant impact on the overall range of the beacons. Due to the limitations of the locations in which the experiments were held, it was not feasible to get the true maximum distance of each of the beacons in the scenarios. However, it can still be seen that at a certain point in each scenario the range at which the beacons are reliable begins to drop off quite substantially.

While these graphs only show the reliable distances of the RadBeacon USB in these scenarios, the maximum distances had a similar pattern, although they were often a few meters larger than the reliable distances.

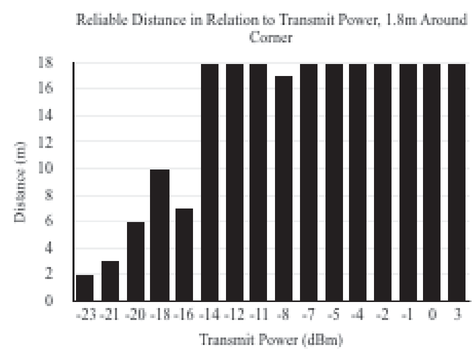

Figure 11. Minimal obstructions around a corner, 184cm along the wall. This graph maps to experiment V.

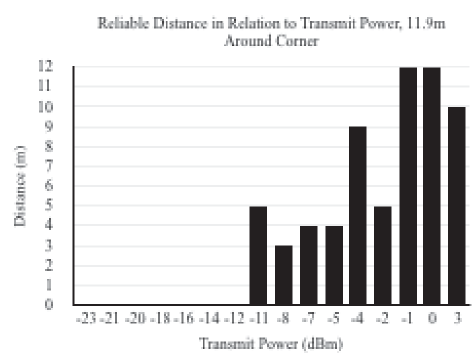

Figure 12. Minimal obstructions around a corner, 1191cm along the wall. This graph maps to experiment VI.

5 Conclusions

In this section, we cover what the findings mean for indoor localization and BLE technology as a whole. Future research possibilities are also mentioned, such as exploring

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other BLE capable technologies and beacons.

The purpose of our research is to examine the impact that the power setting has on the range of BLE beacons. This information influences the development of indoor localization systems.

Indoor localization itself has widely been researched in recent years, though it has yet to become widely implemented in everyday lives as the GPS has been. The more steps taken towards the goal of improving indoor localization means more steps taken towards integrating more useful and innovative technology into our everyday lives.

The ultimate goal in indoor localization research is to have indoor localization systems that are as accessible to the general population as GPS based outdoor positioning is in modern times. This would benefit all sorts of indoor locations, both public and private in a variety of different technological aspects. Indoor localization can also have an imperative role to play in the internet of things and the growth of technology for use by the public in general.

Our experiments all yielded tangible and relevant evidence in an attempt to address the question that this paper tries to answer. Through the above experiments, this paper has confirmed that adjusting the transmit power of the BLE beacons does in fact have an effect on their range and their ability to travel through common obstacles such as walls.

These findings indicate that BLE beacons can be customized even further for ad hoc indoor localization systems. Thus, with a combination of placement techniques, increasingly accurate distance estimation formulas, and manipulation of the transmit power of the BLE beacons, indoor localization using this technology will become more accessible.

Our work only considered the use of two BLE devices, the Android Nexus 5X and the RadBeacon USB. Future research could examine reliable distances on different BLE capable smartphones and different BLE beacons conforming to different BLE specifications.

Of course, when a BLE capable device is not right next to the beacon, there will always be other environmental factors that can have an impact on the reliable range of the BLE beacons. Examining this aspect goes beyond the scope of this paper. Another potential area that future research could touch upon goes with this notion. Quantifying the way in which environmental factors interfere with the overall range of these BLE beacons is another step towards determining the most effective method of setting up a BLE indoor localization system.

Steps could also be taken to research utilizing the above properties of BLE indoor localization noted above in tandem. That is, taking into account placement, formulas, power settings, and environments in order to create the most accurate indoor localization system possible with the current technology. Another goal in this case would be to create a simplified system that would allow anyone to easily implement a BLE system into their indoor environments.

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